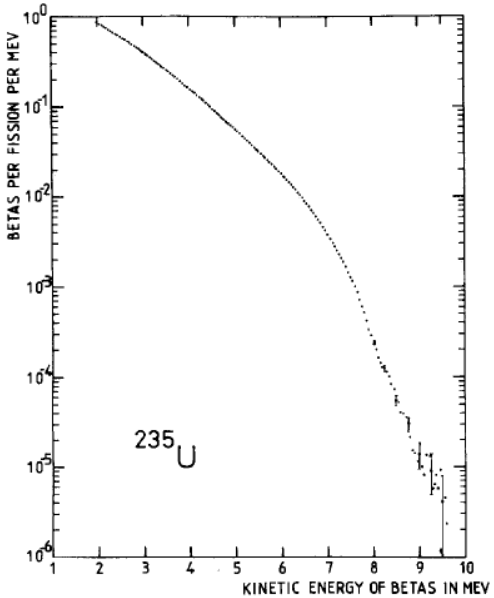
Reactor Neutrino Fluxes and Models

Anna Hayes

Los Alamos
NATIONAL LABORATORY
EST. 1943

5 years ago we thought we knew the antineutrino fluxes

- The antineutrino spectra for ^{235}U, ^{239}Pu and ^{241}Pu have historically been taken from a conversion of the aggregate fission beta measured by Schreckenbach *et al.* at the ILL reactor.



Very challenging measurements because the spectrum spans 5 orders of magnitude over E= 2-10 MeV

Fitted

$$S_\beta(E) = \sum_{i=1,30} A_i S^i(E, E_o^i)$$

$$S^i(E, E_0^i) = E_\beta p_\beta (E_0^i - E_\beta)^2 F(E, Z)(1 + \delta\ )$$

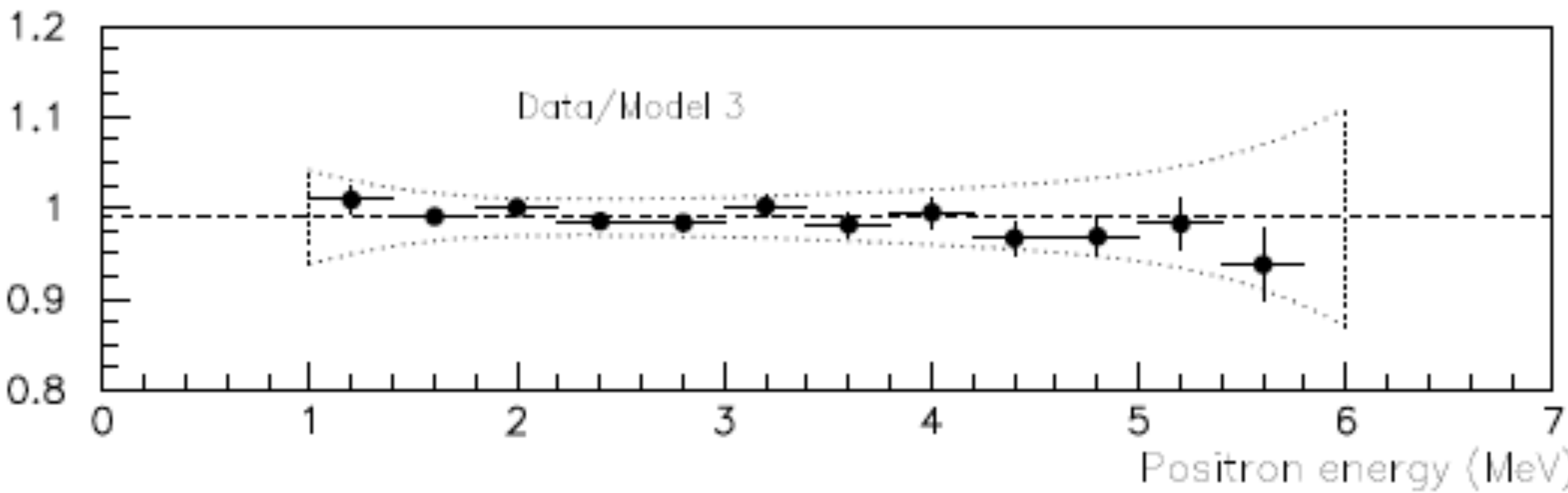
corrections

Spectrum for ^{238}U taken from an ENDF/B-V database calculation, assuming equilibrium burn

$$S(E) = \sum Y_{CF}^{(A_i, Z_i)} S(E, A_i, Z_i) \quad ; \qquad \int S(E, A_i, Z_i)\, dE = 1$$

Cumulative fission yields

Bugey 3 gave us *(false?)* confidence

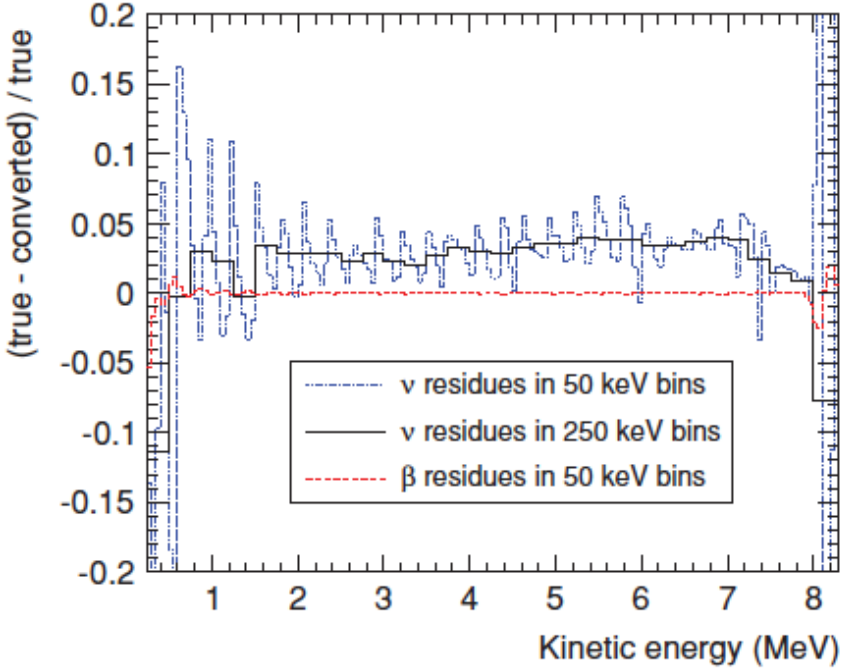


Agreement between Bugey and Schreckenbach was key to small uncertainties being put on the 'Expected' antineutrino spectrum

Two Problems have arisen in the past 4 years - The Anomaly and the 'Bump'

The anomaly:

A new fit to Schreckenbach, with improved treatment of weak magnetism and finite-size corrections, increases the antineutrino spectrum by ~3%

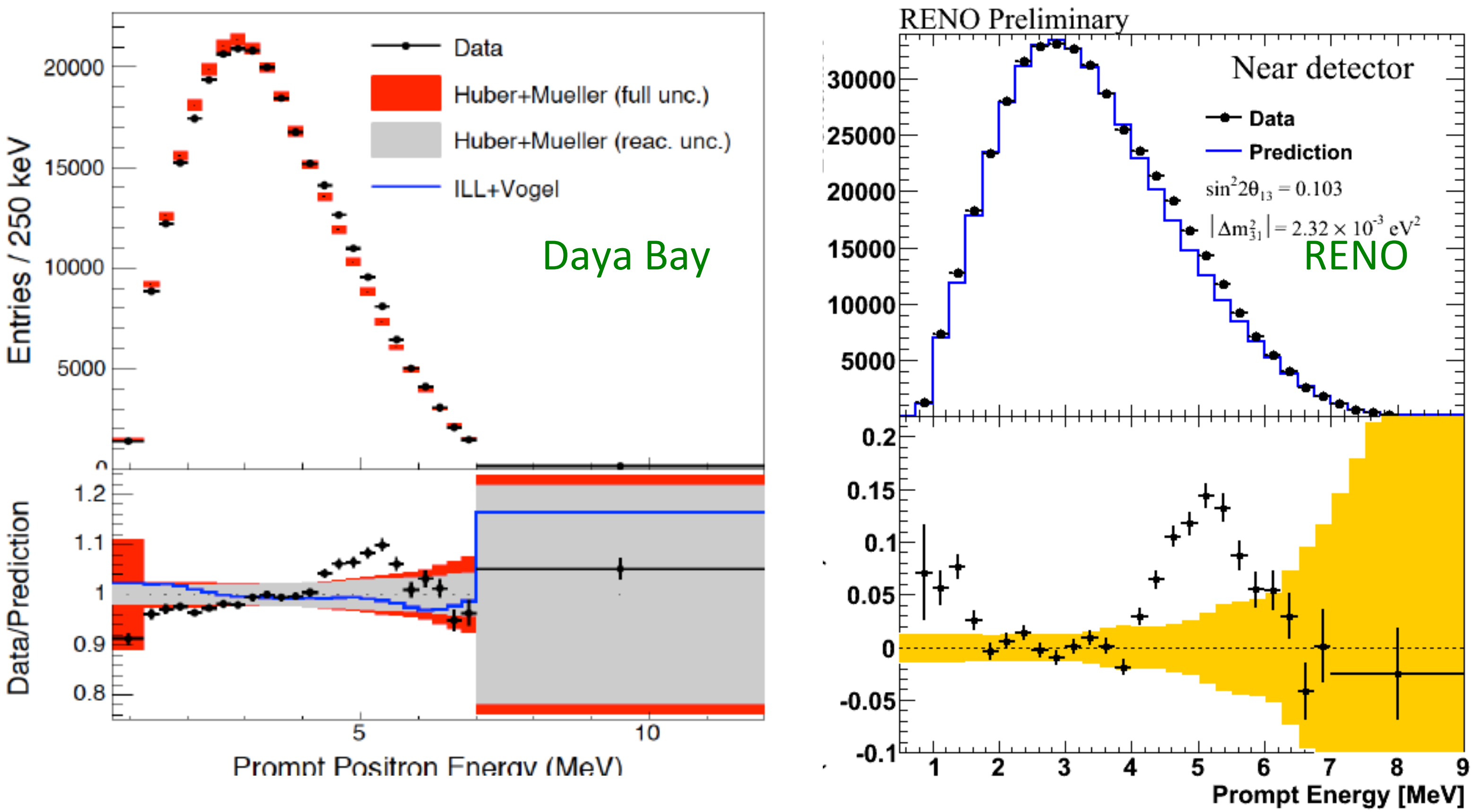


Th. Mueller *et al., PRC 83, 054615 (2011)*

- P. Huber confirms the result*, PRC 84, 024617 (2011)*

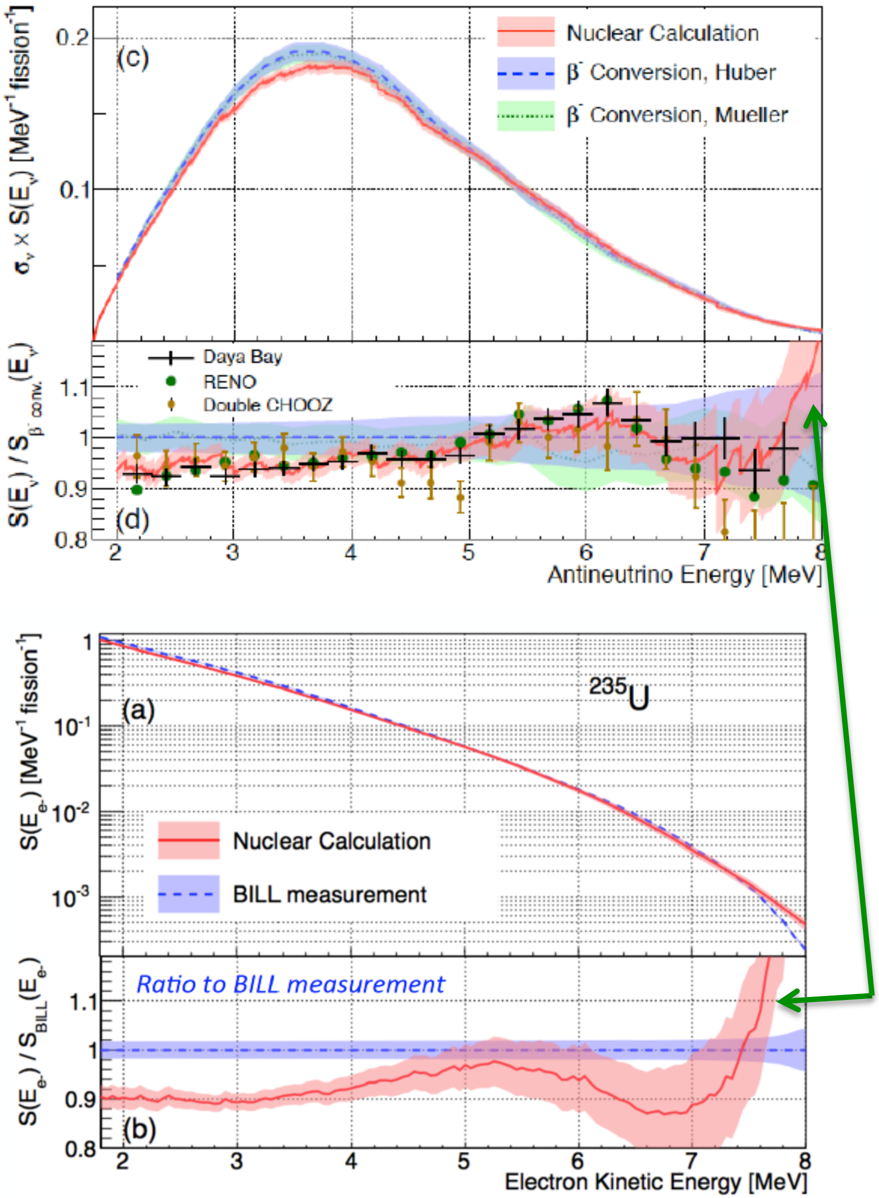
- Hayes et al. point to systematic uncertainties due to forbidden nature of dominant transitions, e.g., weak magnetism often doesn't contribute at all, *PRL* 112, 202501 (2014).

The 'Bump' : refers to the shoulder seen in all modern reactor neutrino experiments at E_{prompt} =4-6 MeV, relative to expectations



The spectra measured at Daya Bay, RENO, and Double Chooz all exhibit a shoulder relative to the predicted spectra of Mueller and Huber

The BUMP is predicted within the ENDF database both in the antineutrino spectra and the beta spectra



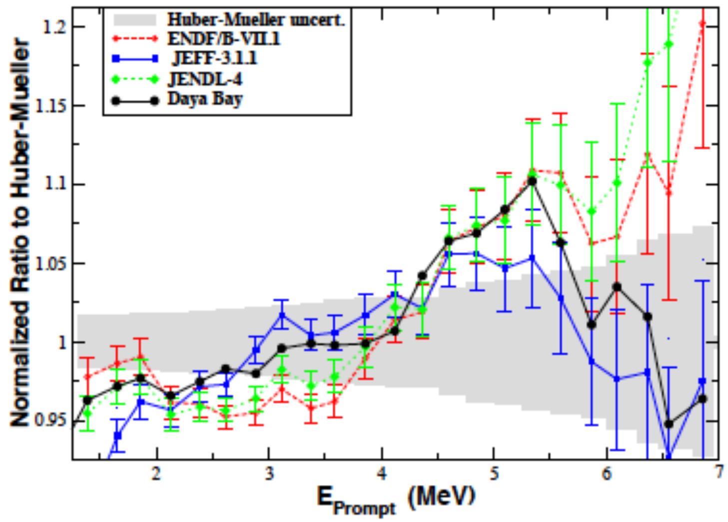
Dwyer and Langford, PRL 114, 012502 (2015)

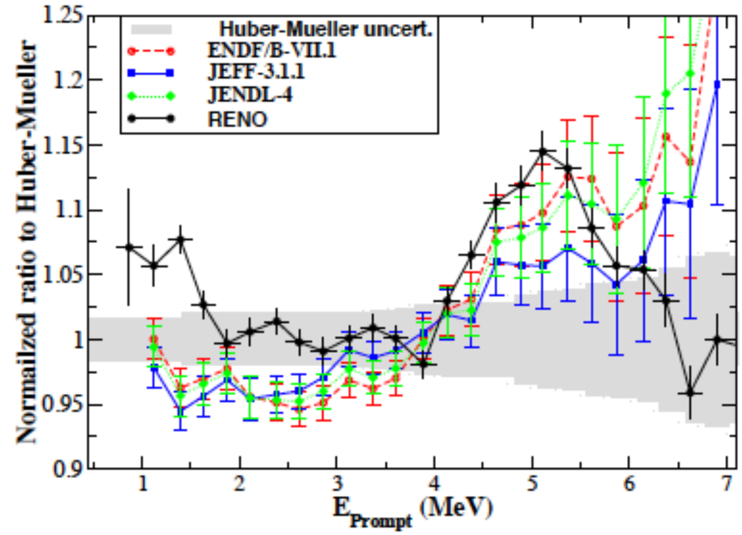
Used ENDF/B-VII decay library and fission yields and a <u>subset</u> of fission fragments

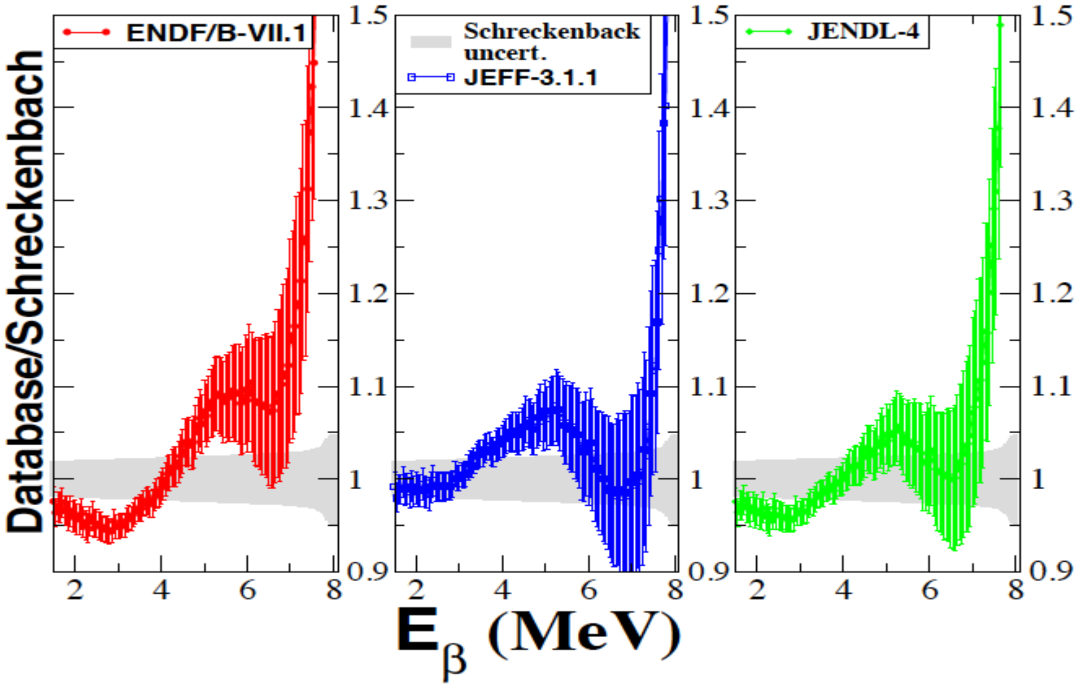
Raises the question: Is there something wrong with the Schreckenbach measurements?

<u>Note</u>: Neither Schreckenbach's original β-spectrum nor the modern antineutrino measurements agree with the database at E>7.0 MeV

When All Fission Fragments are included, problem remains
Also, shows up with every database checked (US, European, Japanese)

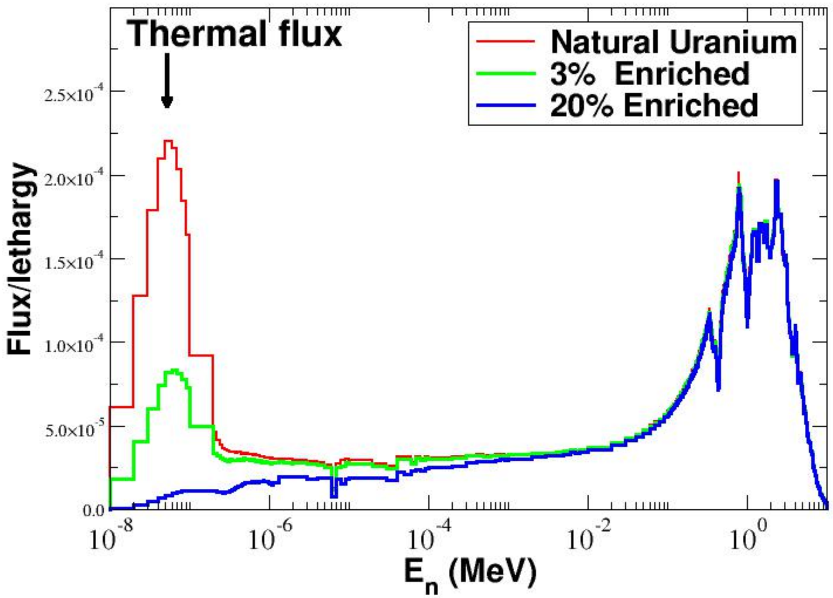


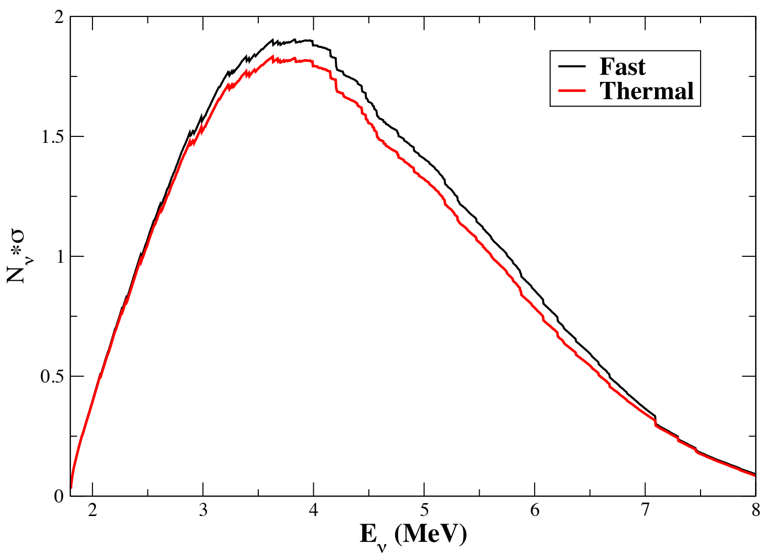




- Absolute and relative database predictions higher than Schreckenbach/ Huber in 4-6 MeV region
- The uncertainties shown are only from the the beta-decay branches
- The differences between the different databases arises from the fission yields
- Uncertainties in fission yields must be much larger than quoted

Hardness of the Neutron Flux Spectrum can be a Factor
- hardens the antineutrino spectrum





ILL has a very thermal spectrum because the moderator is D_2O
PWR reactors will have larger fast component
The more enriched the fuel the harder the neutrons spectrum

Could be part of the source of the 'bump'

What are the best experiments and at which reactors?

Considerations:

1. A new aggregate beta spectrum may not be the answer to some questions
   - It falls off over 5 orders of magnitude in energy region of interest –difficult to measure
   - There appears to be too much uncertainty in converting it to neutrino spectrum
   - To determine the relative normalization of U to Pu, a β-spectrum measurement is not as challenging as an absolute measurement and seems like the way to go

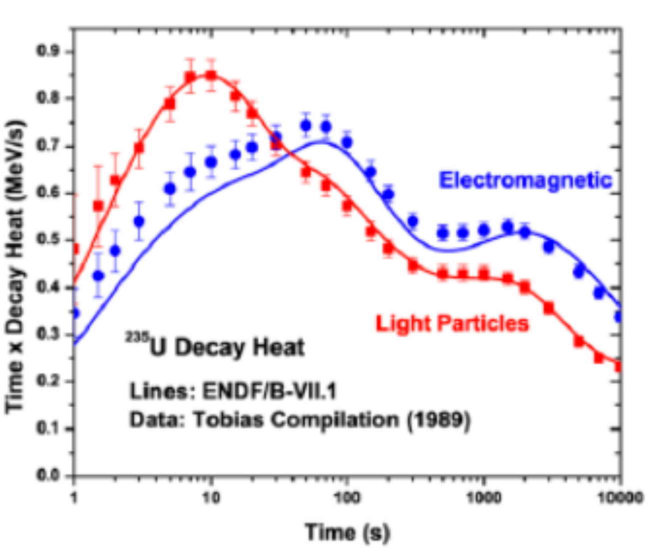
2. Would like a small core but one with a high antineutrino flux
   - Limits us to specialized research or isotope production reactors

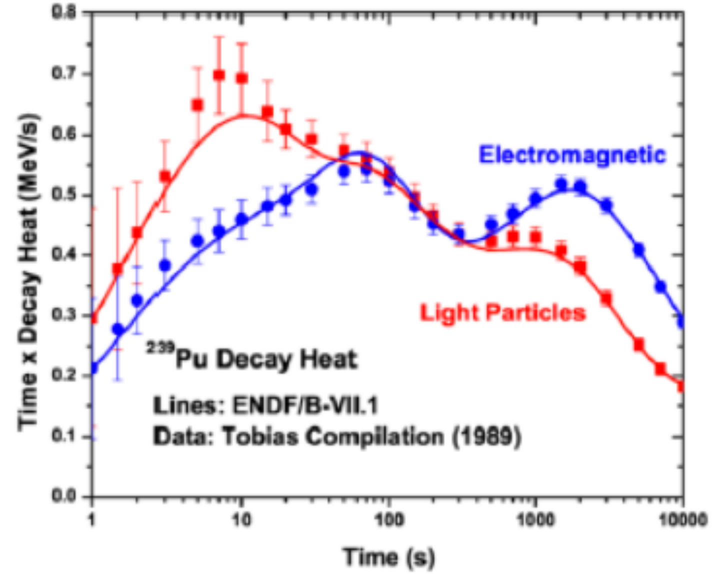
3. The enrichment of the fuel has two effects
   - If highly enriched (~93%), then all fissions come from ^{235}U –nice check of one nucleus
   - The ratio of the fast to thermal flux is maximized – the bump effect gets exaggerated

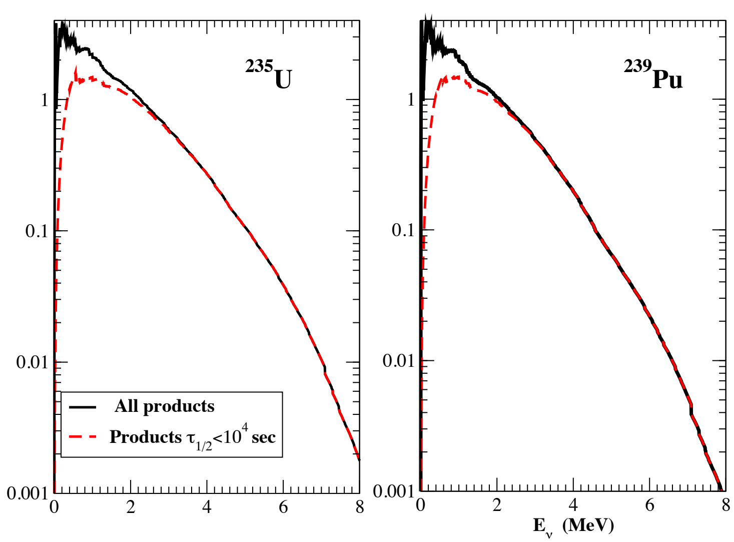
4. Neutron moderation also changes the ratio of fast to thermal flux
   - Schreckenbach experiments at ILL involved a highly thermalized flux – heavy water
   - PWR experiments involve much harder fluxes

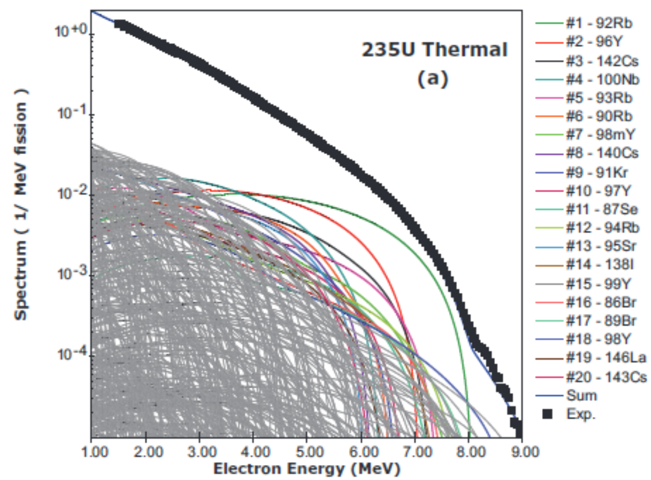
5. Both PROSPECT and SOLID address most questions

An Accurate Determination of the Flux would greatly constrain the Fission Yields that are important for Decay Heat Studies









Sonzogni et al.,
PRC 91 ,01301, (2015)

Several of the dominant nuclei for decay heat also dominate the anti-neutrino flux

What are the main needs for the non-proliferation community?

- Can we determine that a reactor is running when it cannot be detected by satellite heat?

  => The reactor is most likely buried underground

  The challenge is the standoff distance and hence the size of the detector

- Can we detect that a blanket has been inserted into a reactor for undeclared Pu production?

  => Most likely scenario is that blanket is depleted uranium

  => Blanket produces a very small fraction of the fissions

  Challenging

- Certainly need to pin-down the anti-neutrino flux spectra